

Effect of Nozzle Configuration on Thrust of a Novel Turbojet-Turboprop Engine for Small Unmanned Aircraft

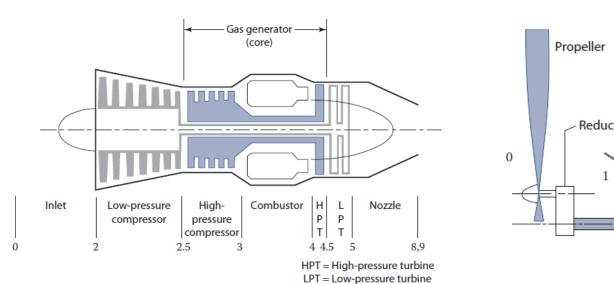


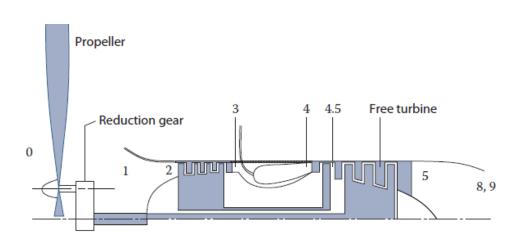
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Abstract

This paper presents the results of testing the effects of nozzle area ratio, nozzle downstream location propeller shape, and propeller size to determine the feasibility of a variable-cycle turboprop/turbojet powerplant for small unmanned applications. The motivation of this project is to inform design decisions for a single aircraft with both high-speed dash and high-endurance loiter capabilities, creating a package that can perform both long range and long-duration surveillance. In this study, thrust was evaluated through static testing of a modified 6.7 horsepower KingTech K45TP engine with an array of turbojet nozzle exit diameters from 1.57in (40mm) to 0.94in (24mm), with offset from the turboprop exhaust exit between 0.75 inches and 1.75 inches. Additional testing was accomplished to measure static thrust with the different nozzle exit diameters and locations in turboprop mode with 2- and 3-bladed, 20-inch diameter propellers. Turbojet mode was achieved by locking the propeller to prevent rotation. Based on initial results, it appears that while the turboprop configuration generates excellent thrust across many nozzle diameters and offsets, the turboprop has difficulty generating usable thrust with the propeller's turbine locked in the flow. Comparison of the propellers indicates that the 3-bladed Biela produced more thrust with no decrement to operability. Future research should consider rocket-assisted take-off for high-speed flight with a folding propeller, rather than attempting to achieve high-speed flight in a turbojet mode. Follow-on developments should include design and implementation of a mechanism for releasing the folding propeller after high-speed flight.

Introduction





Turbojet: Accelerates exhaust flow out of engine core via area reduction nozzle

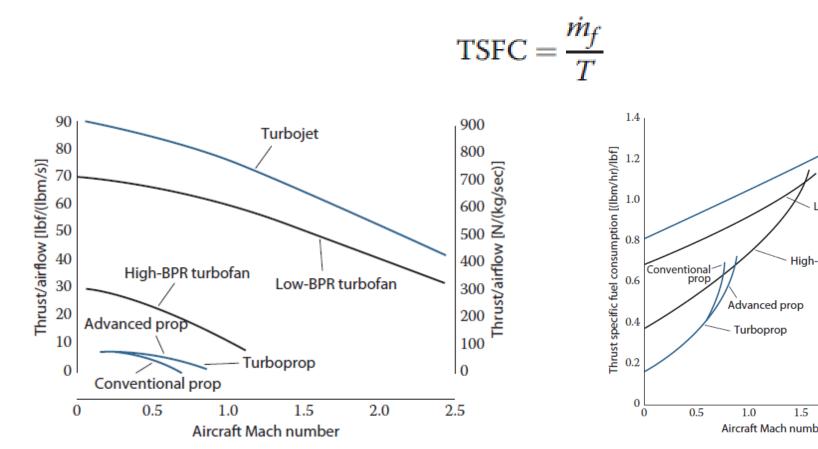
Turboprop: Extracts energy from exhaust flow with a secondary turbine used to turn a propeller

Motivation

Using Newton's Second Law, the thrust produced by an engine is the rate of change in momentum it imparts on the airflow plus the difference in pressure between the inlet and outlet, which can be assumed to be zero.

$$F = \frac{(\dot{m}_0 + \dot{m}_f)V_9 - \dot{m}_0V_0}{\sigma_c} + (P_9 - P_0)A_9$$

Specific thrust is simply the thrust produced per unit mass flow of air. Thrust specific fuel consumption is the rate of fuel mass consumed per unit of thrust produced.



Turbojet:

 Accelerates a small mass flow to a very high velocity—excellent specific thrust, high TSFC

Turboprop:

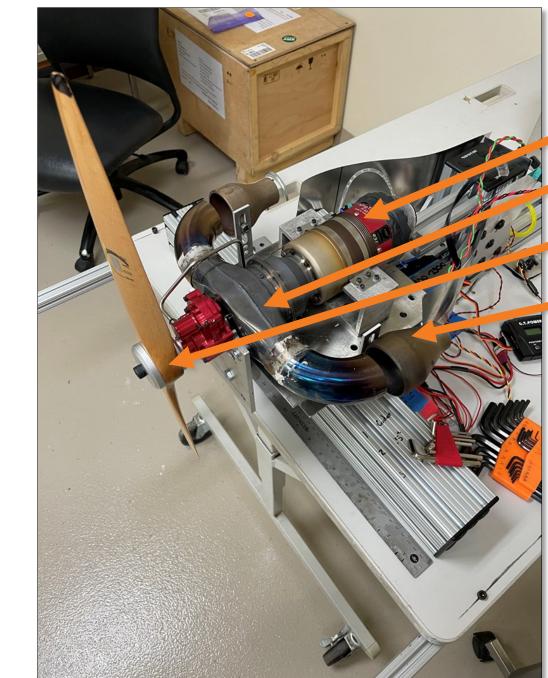
 Accelerates a large mass flow to a relatively low velocity—lower specific thrust, lower TSFC

The ability to choose high specific thrust or high fuel efficiency at will is very desirable.

Procedure

- Tests performed outdoors using a static test stand and a calibrated load cell
- A linear actuator was used to adjust the downstream distance of the nozzles
- Nozzle exit diameters of 24mm, 36mm, and 40mm as well as nozzle downstream positions from 0.5in to 2in were used.
- Tests were also run with 24mm nozzles directly attached to the exhaust in both modes



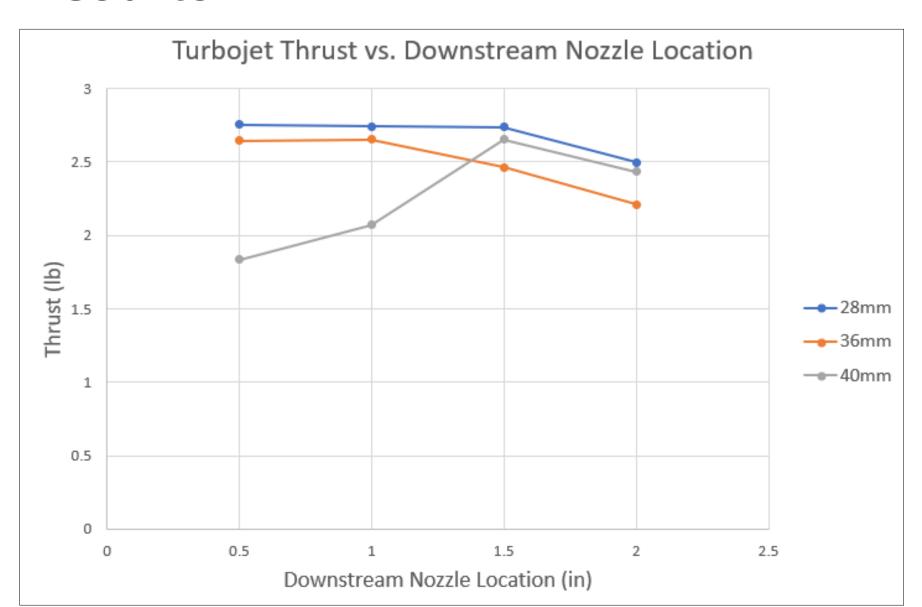


- K45TP engine core
- Exhaust manifold
- 2-blade propeller
- Area reduction nozzles

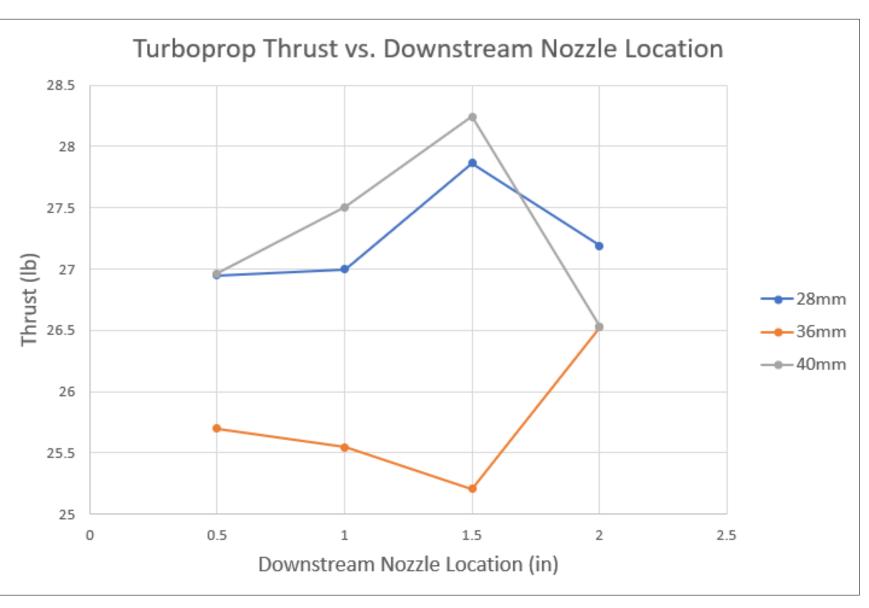


- Nozzle L-brackets
- Servo pushrod
- Bracket subassembly track
- Engine core plate mounts
- Test stand base

Results



This plot shows the results of turbojet testing using nozzles with exit diameters of 28mm, 36mm, and 40mm.



This bar graph displays the ratios between the highest thrust value recorded with a fixed 24mm nozzle and the highest thrust recorded with any nozzle for both modes.

Ratio of 24mm Fixed Nozzle

Thrust and Maximum Mode

Turbojet

Turboprop

This plot shows the results of turboprop testing using nozzles with exit diameters of 28mm, 36mm, and 40mm.

Conclusions

Based on the results, the 28mm nozzle appears to have the best turbojet performance, while the 40mm has the best turboprop performance. However, the most thrust that could be generated in a turbojet configuration is only 33.2% of the 10 lb of thrust that a pure turbojet should produce. This calls the utility of the design without substantial modification into question. For future research, use of the locking system as an engine idle setting in conjunction with a folded propellor, allowing for a compact, rocket-launchable turboprop system seems promising.

References

Mattingly, Jack D. *Elements of Propulsion Gas Turbines and Rockets*. Reston, Va: American Institute of Aeronautics and Astronautics, 2016. Print.